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The Raccoon River Watershed in Iowa has received considerable attention in the recent past due to frequent detections of nitrate concentrations above the federal drinking water standard. This paper econometrically investigates the determinants of variation of nitrate concentrations in the Raccoon River. The analysis relies on a generalized autoregressive conditional heteroscedastic process to model the serial dependence of volatility of the monthly nitrate concentrations in the Raccoon River. Monthly nitrate concentration data from Des Moines Water Works at Van Meter from 1992 to 2008 are used in the study. We found no statistically significant increasing trend in nitrate concentrations over the study period. There are substantial intra-annual variations in nitrate concentrations, and we noted a very strong seasonal pattern. Variations in rainfall and temperature contribute more to the monthly variation in nitrate concentration than do the changes in nitrogen application rates.

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The Raccoon River Watershed (RRW) in Iowa has received considerable attention in recent years due to concerns regarding excessive nitrate (NO_3^-) concentrations in the Raccoon River. Frequent detections of NO_3^- concentrations above the federal drinking water standard of 10 mg L^{-1} have raised questions about the sources of NO_3^- in the Raccoon River and, more specifically, about the effect of agricultural practices in the watershed on in-stream NO_3^- concentrations. Also, some sections of the Raccoon River have recently been identified in Iowa's Federal Clean Water Act 303(d) as completely or partially impaired waters because of these elevated NO_3^- levels. The Federal Water Pollution Control Act Amendments of 1972 is generally called the Clean Water Act. Its objective is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. The Iowa Department of Natural Resources is the state agency responsible for water quality management in the state of Iowa (see http://www.iowadnr.gov/water/standards/index.html for more details).

The RRW is a part of the Mississippi River drainage basin, and nutrient runoff that is carried by the river system has been cited as a contributing factor to the hypoxic conditions that exist in the Gulf of Mexico (Rabalais et al., 2002). Kalkhoff et al. (2000) reported that NO_3^- concentrations from several Iowa watersheds are among the highest observed in the Corn Belt. Agricultural production is a predominant use of a significant portion of the land in the RRW and is a primary driver of the local economy within the watershed. More than half of the crop acres in the watershed are typically planted to corn, which is associated with annual applications of commercial fertilizers and manure. Intensive agriculture is often reported as the primary source of water quality degradation in the river despite the significant increases in nutrient utilization efficiency that have been achieved for corn production (Burkart and James, 1999). Nutrient outputs from animal agriculture have also been reported as a significant source of nutrient impairment of the Raccoon River (Keeney and DeLuca, 1993).

In recent years, agricultural researchers have developed theoretical and empirical tools designed to evaluate the effects of

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Abbreviations: ARCH, Autoregressive Conditional Heteroscedastic; DMWW, Des Moines Water Works; GARCH, Generalized Autoregressive Conditional Heteroscedastic; RRW, Raccoon River Watershed.

nonpoint pollution sources on in-stream water quality. Because of their diffuse origins, these agricultural nonpoint source emissions are difficult to measure on site, creating challenges for those involved in designing mitigation policies (Kling, 2010). Much of the research work has focused on simulation models, such as the Soil and Water Assessment Tool (SWAT) framework (Jha et al., 2006). The SWAT model was developed to predict the impact of agricultural or land management on water, sediment, and agricultural chemical yields in watersheds (Arnold et al., 1998). SWAT has been successfully used for many different types of hydrologic, stream quality, and watershed management applications (Gassman et al., 2007). SWAT is physically based and requires data about weather, soil properties, topography, vegetation, and land management practices in the watershed. It does not incorporate regression equations to describe the relationship between the dependent variable and independent variables. SWAT does not need historical water quality monitoring data (e.g., river gauge data). Hence, SWAT is very sensitive to the initial parameter values that are used to calibrate the model and that are based on simulations with little connection to the actual data (Gassman et al., 2007).

In addition to the SWAT model, there have been significant research efforts aimed at understanding the impact of agricultural practices on water quality factors. There are many studies in the applied hydrology and water quality literature that examine the statistical significance between agricultural land use and NO_3^- concentration patterns in the RRW. Notable contributions include Keeney and DeLuca (1993), Schilling and Libra (2000), Schilling and Zhang (2004), Schilling and Lutz (2004), Mausbach and Dedrick (2004), and Hatfield et al. (2009). These studies share one important finding: NO_3^- concentrations are positively correlated to the acres of land devoted to row crops in the watershed. Kling et al. (2007) provided comprehensive discussions of these and other early contributions.

Hatfield et al. (2009) analyzed NO_3^- concentrations in the RRW for the past 70 yr and tried to correlate NO_3^- concentrations to the changes in agricultural characteristics within the watershed. Their study examined the interrelationships among historical NO_3^- concentrations and NO_3^- fertilizer use, animal production, crop yields, land use changes, and precipitation patterns and found that mean annual NO_3^- concentrations in the RRW have been increasing since 1970 in spite of no significant change in NO_3^- fertilizer use for the past 25 yr. Results showed a significant correlation between the decline in the land area cropped to small grains and hay crops within the watershed and the increase of NO_3^- since 1970. They reported that changes in cropping patterns were more significant than changes in NO_3^- fertilizer use and annual rainfall variation in affecting in-stream NO_3^- load. However, the study by Hatfield et al. (2009) was based on descriptive statistics and graphical presentation.

Although headway has been made and the previous studies have contributed immensely to our knowledge about the dynamics of the RRW, much more work remains to be done. Until recently, few studies have used time series analyses on NO_3^- concentration data partially due to the fact that most records are of insufficient length for time series analysis. Atasoy et al. (2006) used a spatially autoregressive model to analyze the effects of urban water residential construction and land use on water quality in the upper Neuse River basin in Wake County, North Carolina. Their results showed that residential development in the watershed had statistically significant positive effects on NO_3^- loadings.

Unlike Atasoy et al. (2006), our study focuses on nonpoint-source pollution. We examine what factors relate to the observed NO_3^- variation in the Raccoon River over the past 20 yr. Variation in observed NO_3^- concentrations is not solely caused by differences in nitrogen fertilizer application (Kaspar et al., unpublished observations). Rather, it is due to a combination of temperature and precipitation patterns as well as soil management practices and the physical, chemical, and biological features of soil. Hence, reduction in NO_3^- concentrations is more than just a matter of controlling fertilizer application rate, placement, and timing of application. Overall, NO_3^- losses from agricultural watersheds are complex interactions of the hydrologic properties of the watershed and land use practices within the watershed (Hatfield et al., 2009).

The relationship between NO_3^- concentration in water and nitrogen inputs to crop production is of vital importance in designing an agricultural production and environmental policy in Iowa and the United States. A balance is being sought between lowering NO_3^- concentration and socioeconomic goals. Particularly, the production of adequate food and fiber to meet global demand is an increasingly critical consideration that needs to be addressed by policymakers as they consider environmental policies and regulations to improve water quality but which may include modifications to existing nutrient management regimes. There is no unified answer to the question of how to balance these competing goals. Recent actions by the Iowa Department of Natural Resources indicate that they may be working to implement policies that could further restrict nutrient use in various watersheds as part of the overall water quality program (see http://www.igsb.uiowa.edu/wqm/Publications/Reports for more details). This move could have negative economic consequences for farmers in Iowa and throughout the Corn Belt without providing the anticipated improvements in water quality if the actual causalities for variations in water quality factors are not adequately understood.

Iowa farmers have undertaken significant actions in recent years to protect Iowa's soil and water resources with voluntary, incentive-based programs. These actions, combined with technological advances in seed genetics and agricultural production practices, have allowed for significant increases in crop production with minimal increases in nitrogen inputs. However, these improvements in input efficiency have not been sufficient to satisfy the concerns by environmental advocates that nitrogen applications within the watershed are too high. Given these interesting public issues, there is an urgent need for applied scientific research to inform the public debate in this area. Hence, the purpose of this study is to empirically test the significance of selected variables of interest to explain the fluctuations in NO_3^- concentration that are occurring in the Raccoon River.

The objective of this study is to assess the factors affecting the monthly NO_3^- concentrations in the RRW. Only a few studies have been done to analyze in-stream water quality and agricultural practices using econometric methods (Taylor, 1973). This is surprising given the sensitivity in the public debate emanating from the water quality problems associated with row-crop agriculture and livestock operations in the Corn Belt and

Upper Mississippi River Basin. State regulators recently began to consider the role of nonpoint-source pollution in establishing the total maximum daily loads for some listed waterways, including the Raccoon River. It is essential to understand how the river system has responded to changes in nitrogen applications and weather conditions in the past before embarking on a program to set regulatory standards that would impose economic burdens on Iowa's communities.

In this paper, we propose a new method for analyzing in-stream NO_3^- concentration data. An original feature of our model is that NO_3^- concentration exhibits variances that change through time. The GARCH models are an appropriate choice to model these changing variances, as is well documented in financial statistics literature. The novelty of this study is the application of a GARCH model to quantify the relationship of variables for which the variance changes through time.

What determines the variation of NO_3^- concentrations among a list of presumed relevant factors is a timely research question given the fact that agricultural production is increasingly becoming a complex arena with ever-changing demands on agriculture to supply food, feed, fiber, and fuel. Some believe these demands are at odds with desired levels of water quality, leading to new questions that need policy solutions that are economically viable and environmentally friendly. To find such solutions, policymakers need to know what causes variation in observed water quality factors, such as in-stream NO_3^- concentration.

Model Description

This analysis uses time series econometric techniques to examine the factors determining the NO_3^- concentrations in the Raccoon River. Serial correlation (autocorrelation) is a frequent problem in the analysis of time series data. Various factors can produce residuals that are correlated with each other, such as an omitted variable or the wrong functional form. If the problem cannot be resolved by improved model specification, then we need to correct for the influence of the autocorrelation through statistical means. We first identify the autocorrelation in the NO_3^- concentrations data by looking at the sample autocorrelation function and partial autocorrelation plots. To systematically address this issue, an autoregressive model is used to model the NO_3^- concentrations in the mean equation of the GARCH model. The second-order autoregressive model was selected by considering the minimum of the Akaike Information Criterion (Akaike, 1974). By doing so, we have corrected the serial correlation in the disturbances.

The use of time series econometric techniques to analyze the causal relationships among water quality, land use, weather variable, and nutrient use in the RRW has not been done before with watershed-scale data. The advantage of this approach is that it explicitly allows us to control for distributed time lags and autocorrelated errors while addressing heteroscedasticity in the error structure in the water quality data. As a result, we are able to provide more precise estimates of the quantitative links between variations in NO_3^- concentration levels and their determinants.

Generalized Autoregressive Conditional Heteroscedastic (GARCH) models are widely used to study the volatility of time series data, particularly in finance, because they provide a good approach to conditional variance modeling. More specifically, GARCH is a time series technique used to model the serial dependence of volatility. This study uses the GARCH process to model the distribution of NO_3^- concentrations in the Raccoon River. The GARCH model is an extension of the Autoregressive Conditional Heteroscedastic (ARCH) model originally developed by Engle (1982).

The ARCH model was developed to capture the effect of changing variance on the model. The time-dependent conditional variance is modeled as a linear function of past realization of the disturbance term. This is motivated by the assumption that larger disturbances cluster together (i.e., a large disturbance today increases the chances of a large disturbance tomorrow). The GARCH model allows current and lagged conditional variances, as well as past realization of the disturbance term, to affect the sample data generating process.

The GARCH model can be extended by assuming a different distributional assumption on the disturbance term. This study uses a GARCH-normal process whereby it is assumed that the disturbance term follows a normal distribution. Bollerslev (1986) suggests that the simplest GARCH model is the GARCH (1, 1) process. We follow Bollerslev's proposition.

Let y_t be a column vector of NO_3^- concentrations, x_t is a matrix of observations of explanatory variables, β represents a vector of parameters to be estimated, and ε_t is a vector of disturbance errors:

$$y_t = x_t\beta + \varepsilon_t \qquad [1]$$

Then ε_t is split into a stochastic piece z_t and a time-dependent standard deviation σ_t, so that

$$\varepsilon_t = \sigma_t z_t \qquad [2]$$

where z_t is distributed independently and identically with 0 mean and with standard deviation equal to 1, and

$$\sigma_t^2 = \alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \alpha_2\sigma_{t-1}^2 \qquad [3]$$

and where $\alpha_0 > 0$, $\alpha_1 > 0$, and $\alpha_2 > 0$.

Equation [1] is known as the conditional mean equation, and Eq. [3] is known as the conditional variance (or variance) equation. According to the GARCH (1, 1) model, the conditional variance is equal to a linear function of one period-lagged squared error (ε_{t-1}^2) and one period-lagged conditional variance (σ_{t-1}^2).

By introducing appropriate exogenous variables, the basic formulation of the mean equation (Eq. [1]) leads to the following model:

$$\begin{aligned} Y_t &= \beta_0 + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \beta_3 \mathrm{FLOW}_t + \sum_{i=0}^{2}\gamma_i \mathrm{RF}_{t-i} \\ &+ \sum_{i=0}^{2}\delta_i \mathrm{TEM}_{t-i} + \sum_{i=0}^{6}\theta_i \mathrm{FER}_{t-i} + \tau_1 \mathrm{NRE}_t + \tau_2 \mathrm{POP}_t + {}_3 T_t + \varepsilon_t \end{aligned} \qquad [4]$$

where Y_t is the average NO_3^- concentrations in the Raccoon River in month t; FLOW_t is the average water flow rate in the Raccoon River in month t; RF_t is the average rainfall in the Raccoon River Watershed in month t; TEM_t is the average temperature in the RRW in month t; FER_t is the total nitrogen fertilizer application in the RRW in month t; NRE_t is the total nitrogen uptake from corn (removal through crop growth and harvest) in the RRW in month t; POP_t is the total population in the RRW in month t; T_t is time in months t; and ε_t is the error term.

Description of the Raccoon River Watershed and the Data used in the Study

The Raccoon River watershed in west central Iowa covers approximately 9397 km^2 of land with significant intensive agricultural production (Fig. 1). This watershed is composed of cropland (75.3%), grassland (16.3%), forest (4.4%), and urban area (4.0%) as indicated by Jha et al. (2006). The Raccoon River and its branches drain all or parts of land from 17 counties in the state of Iowa. Its origin is in Buena Vista County in Iowa, and it travels approximately 300 km before it converges with the Des Moines River in the City of Des Moines. The Raccoon River is a primary source of drinking water for approximately 400,000 people in central Iowa.

Water quality data for the Raccoon River were obtained from the Des Moines Water Works (DMWW). Daily NO_3^- concentrations records from the United States Geological Survey (USGS) gauging station at Van Meter, Iowa were collected at the DMWW for the 1992–2008 period. For this analysis, monthly NO_3^- concentrations are derived by computing a simple average of daily records for respective months (Fig. 2). Since 1974, daily NO_3^- levels have been measured by the DMWW; however, there are some data missing for some days in a given month. The DMWW records NO_3^- level at a frequency depending on the

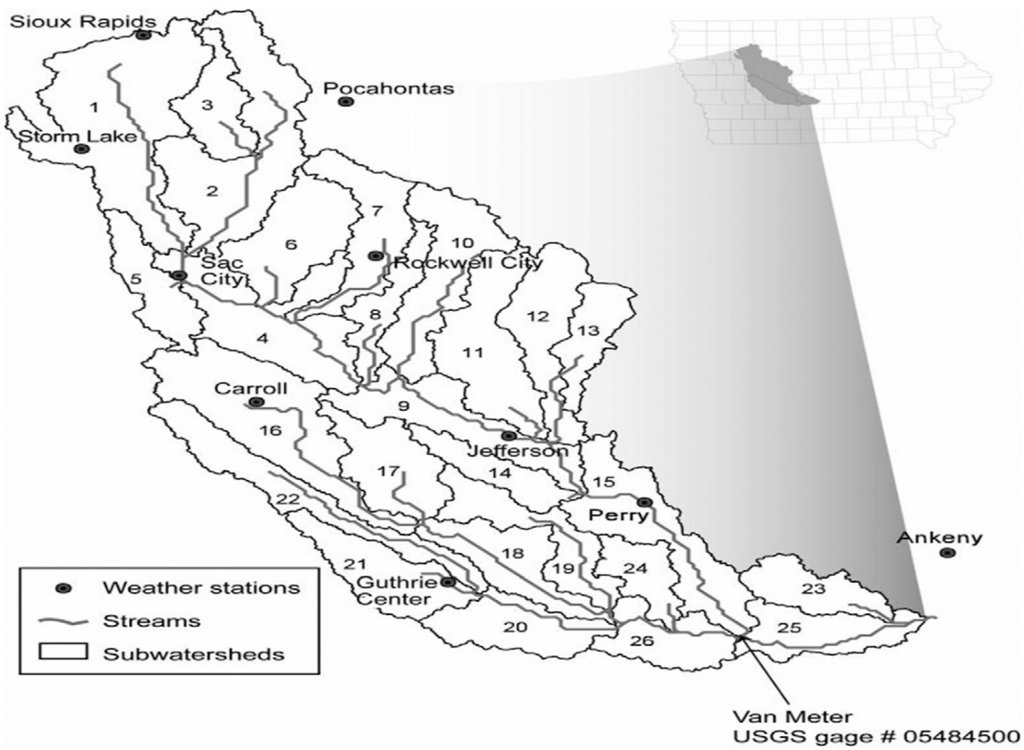

Fig. 1. Raccoon River watershed location within Iowa (source: Jha et al., 2006).

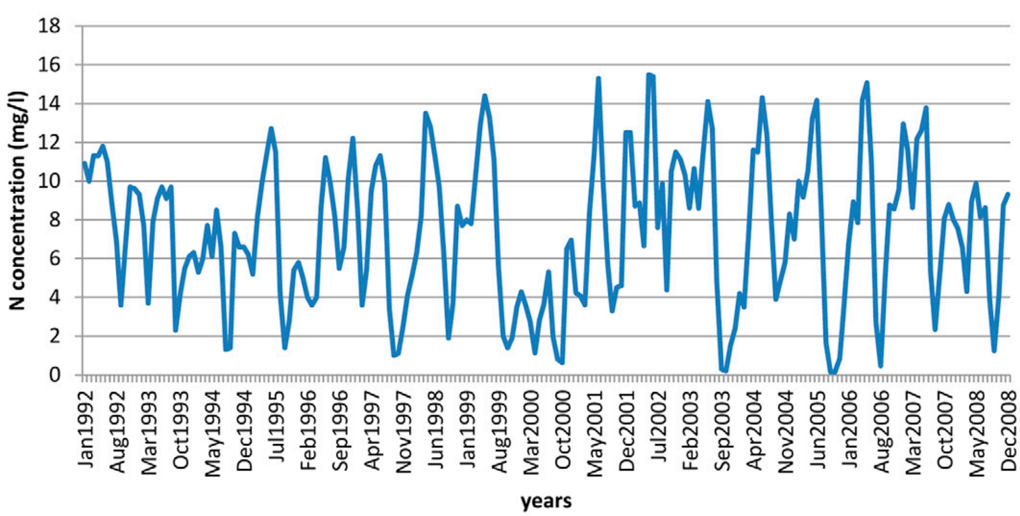

Fig. 2. Monthly NO_3^- concentrations in the Raccoon River Watershed 1992–2008 (source: Des Moines Water Works, 2010).

NO_3^- levels in the Raccoon River generally daily but not less than weekly. Nitrate concentrations data are reported as mg L^{-1}.

Water flow rate data were obtained from the USGS. The USGS has recorded daily average flow rate data at the Van Meter gauging station, and the average monthly flow was calculated by computing a simple average of daily flow rate records. Flow data are reported as $m^3 s^{-1}$. Meteorological data for the Raccoon River watershed were obtained from the National Climate Data Center. Daily rainfall data across the watershed were estimated by calculating the average daily rainfall amount across all gauging stations within the watershed. Then daily data were aggregated into monthly totals for this study. Average daily temperature was used to estimate the average monthly air temperature within the watershed.

Annual corn acreage and annual corn yield for each county within the watershed were obtained from the National Agriculture Statistics Service of the United State Department of Agriculture (USDA). The corn acreage, assumed to be evenly dispersed throughout the respective county, for each county in the watershed was computed based on the percentage of land of each county contained within the watershed. Total corn production for each county was calculated by the corn area multiplied by the corn yield for the year as reported by the USDA. Total NO_3^- uptake from corn was calculated by assuming that corn grain contains, on average, 7% crude protein and that the protein is comprised of 16% nitrogen (Morrison, 1961).

Livestock numbers for hogs, cattle, turkeys, sheep, and chickens were obtained from the USDA. The number of livestock contained within the watershed was derived by prorating individual county livestock numbers based on the percent of the land in the county contained in the watershed. Livestock numbers were converted to equivalent animal units, with one animal unit being defined as an animal with 1000 pounds live weight (USDA animal equivalent factors by livestock species is provided by the Indiana Department of Environmental Management). County livestock numbers were aggregated to get an estimate for the total animal units within the watershed. We then adopted the methodology of the Iowa Department of Natural Resources for estimating manure–NO_3^- applied to crop acres. To estimate the actual level of manure-applied NO_3^- in the RRW, the total manure-applied NO_3^- in each county was prorated by the percent of the county that is within the watershed. This methodology assumes an even dispersion of livestock throughout the county.

Commercial NO_3^- fertilizer application data were obtained from several sources. The total amount of commercial NO_3^- fertilizer applied within the watershed is calculated as the sum of total fertilizer sales for all 17 counties within the watershed with the assumption that all fertilizer sold within the county was applied within the county. The fertilizer data were obtained from the Iowa Department of Agriculture and Land Stewardship with the commercial fertilizer segregated by fertilizer type (see http://www.agriculture.state.ia.us/feedAndFertilizer/fertilizerDistributionReport.asp for more details).

From the data received from the Iowa Department of Agriculture and Land Stewardship, we combined the NO_3^- component of each fertilizer type and multiplied it by the tonnage sold for each type to derive total pounds of NO_3^- sold. Consistent with the methodology used by the Iowa Department of Natural Resources nutrient budgeting project, it is assumed that 85% of all NO_3^- fertilizer sold in the state is applied to land devoted to corn production and that the remaining 15% is applied to crops other than corn and to noncrop uses. After calculating the total NO_3^- sold in the state by fertilizer type, we created an average index of a county's yield to state yield to estimate what the NO_3^- application rate would be at the county level. For example, in 2002, Adair County's corn yield was 9575 kg ha^{-1}, whereas the state corn yield for the same year was 10,187 kg ha^{-1}. This gives us a yield index of 0.94 (9575/10187) for the year 2002 in Adair county. This gives us a yield index of 0.947 (154.3/163.0) for the year 2002 in Adair county. We calculate the average yield index for each county within the RRW for each of the years covered by the study. We then use these indices to estimate what the NO_3^- application was during those years by multiplying the respective yield indices by the state level NO_3^- application rate to arrive at county level NO_3^- application rate per bushel. After calculating the NO_3^- application rate per bushel, we multiply the yield by this index to arrive at a NO_3^- application rate per acre. Again using Adair County as an example, for the year 2002, the NO_3^- application rate per bushel is calculated as follows: 13 g NO_3 kg^{-1}; multiplying Adair County's average yield for the year 2002 (9575 kg ha^{-1}) gives us an estimated 127.9 kg NO_3^- ha^{-1} for the county.

After estimating the NO_3^- application rate (kg ha^{-1}) for each county for each year, we multiplied these rates by the planted corn acreage for each county to obtain the total NO_3^- (kg) applied to corn planted each year. We then adjusted the total estimated applied NO_3^- in each county by the proportion of that county that is in the RRW (i.e., 0.1% in Adair County). County NO_3^- applied data for commercial and manure NO_3^- were aggregated to estimate the total NO_3^- applied within the watershed. We assume the distribution of monthly NO_3^- application as depicted in Fig. 3.

Empirical Results

This study covers the period from the beginning of 1992 to the end of 2008. Table 1 shows the parameter estimates of the mean equation and the variance equation obtained from the GARCH model. There is no statistically significant time trend in NO_3^- concentrations in the Raccoon River for the period from 1992 to 2008. This finding reinforces the results reported by Schilling and Zhang (2004). However, there is substantial intra-annual variation in NO_3^- concentration. Monthly NO_3^- concentrations display seasonal behavior where a certain basic pattern tends to be repeated at regular seasonal intervals each year (e.g., monthly NO_3^- levels are higher in spring months than during any other time of the year; see Fig. 4). Hence, we incorporated quarterly seasonal dummy variables in the estimation of Eq. [4] to capture the seasonality in the data. Because the estimated coefficients for the seasonal dummies are not statistically significant, these are not reported in Table 1. The estimated SPRING and SUMMER dummies' coefficients are positive, and the FALL dummy coefficient is negative. These coefficients are not statistically significant at the 0.05 level. Given the fact that winter is the default, we expected positive signs in the spring and summer because these two seasons exhibit higher NO_3^- concentrations compared with the winter. Similarly, we expected negative a sign

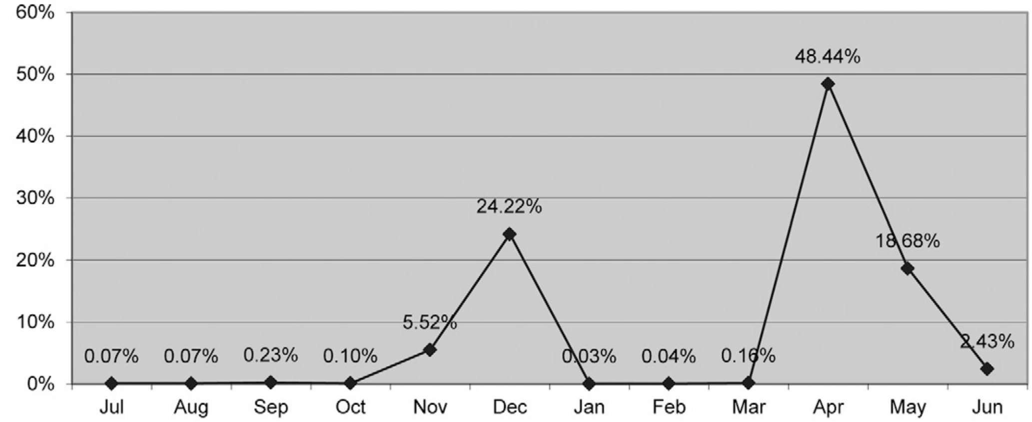

Fig. 3. Distribution of monthly commercial fertilizer application in the Raccoon River watershed (source: Agriculture's Clean Water Alliance of Iowa, unpublished data, 2010).

in the fall because the fall season exhibits relatively low NO_3^- concentrations compared with winter.

For the high volatility of the NO_3^- concentration, the GARCH model is more suitable for evaluating the time series data than other time series models. Estimation of the GARCH model is achieved by using a standard maximum likelihood method. Parameter estimates have expected signs and show mixed statistical significance. The previous month average NO_3^- concentrations have positive statistically significant effects. Both current month rainfall and previous month rainfall have positive statistically significant effects on current NO_3^- concentration in the river. This is consistent with the fact that tile drainage is

Table 1. Estimates of the Generalized Autoregressive Conditional Heteroscedastic model, 1992–2008 (dependent variable is average monthly nitrate concentration).

Variable	Lag	Parameter estimate	Short-run implied elasticities†	Long-run implied elasticities†
		Mean equation		
Constant		3.2270 (32.8058)‡		
NO_3^- concentration	−1	0.7370** (0.0129)	0.7358	0.7358
	−2	−0.0729 (0.0838)		
Water flow rate (t)		−0.0031 (0.0035)		
Precipitation (t)		0.0124* (0.0051)	0.1333	0.1333
	−1	0.0163** (0.0038)	0.1727	0.2695
	−2	−0.0045 (0.0032)		
Temperature (t)		0.0058 (0.0453)		
	−1	0.0706* (0.0249)	0.6110	0.6484
	−2	−0.0498 (0.0259)		
Total NO_3^- fertilizer application (t)		1.75e-08 (1.39e-08)		
	−1	3.05e-08 (2.09e-0.8)		
	−2	4.49e-08* (2.15e-08)	0.0863	0.1454
	−3	5.38e-08* (2.02-e08)	0.0997	0.1841
	−4	4.40e-08* (2.61e-08)	0.0815	0.2070
	−5	3.72e-08* (1.23e-08)	0.0688	0.2079
	−6	2.38e-08 (1.27e-08)		
Plant NO_3^- uptake (t)		−1.28e-08 (4.00e-08)		
Population (t)		−6.19e-05 (2.98e-04)		
Time (t)		0.0021 (0.0255)		
R^2		0.5091		
Log-likelihood		−426.9810		
		Variance equation		
Constant		2.3261* (0.8122)		
$\varepsilon_{t-1}{}^2$		0.4318 (0.2520)		
$\sigma_{t-1}{}^2$		0.1490 (0.1046)		

* Statistical significance at the 0.05 level.

** Statistical significance at the 0.01 level.

† Calculated at their mean values.

‡ Standard errors are in parentheses (heteroskedasticity consistent standard errors according to Bollerslev and Wooldridge, 1992).

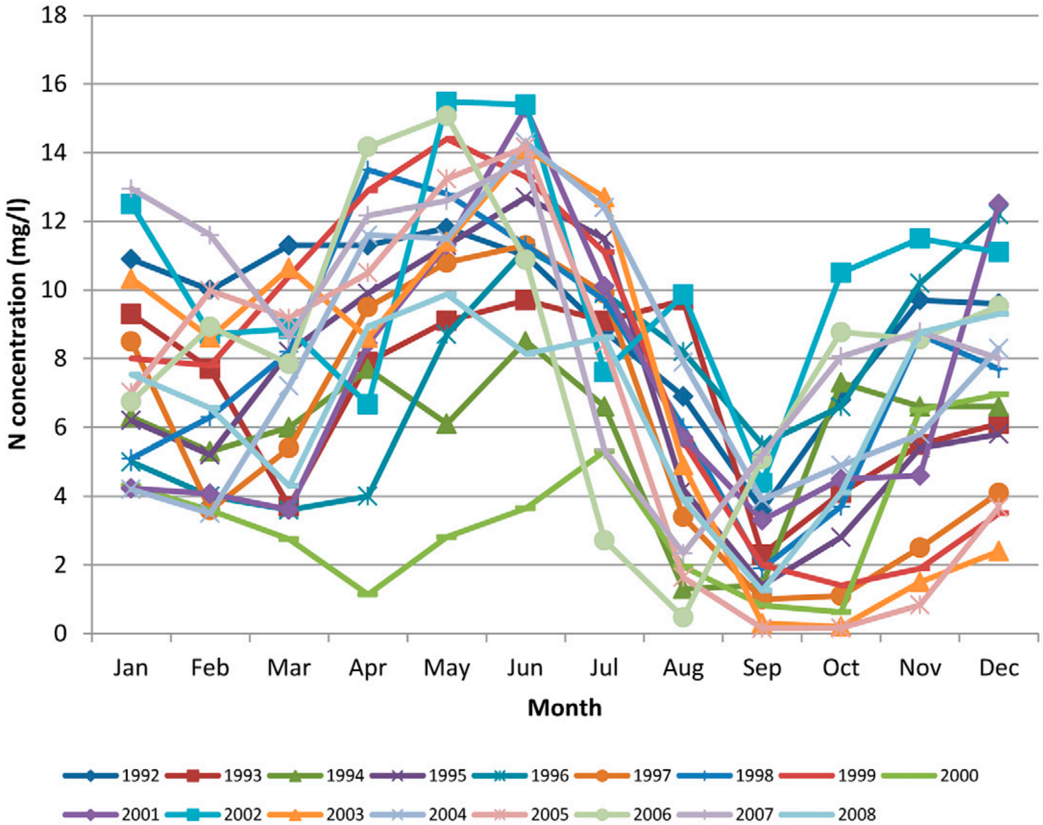

Fig. 4. Seasonal patterns in NO_3^- concentrations in the Raccoon River (source: Des Moines Water Works, 2010).

prevalent throughout the watershed (over 40% of the land area is subsurface drained) and rainfall moving through the soil profile carries soluble nitrogen into streams.

Stream flow is not statistically significant and has a negative sign. One explanation for the negative sign is that a higher water flow rate tends to dilute NO_3^- concentrations. According to Hatfield et al. (2009), increases in rainfall are positively related to increases in stream flow in the watershed. Schilling and Zhang (2004) also reported that high base flow and stream flow due to high rainfall are related to nitrogen loss from the watershed.

The estimated parameter using the previous month's temperature is positive and statistically significant. This shows that the higher ambient air temperature in the watershed tends to result in a higher discharge of NO_3^- to streams. Higher temperatures, which result in higher microbial activity within the soil profile, are likely to release organic nitrogen in the soil and can facilitate more rapid conversion of applied nitrogen forms to water-soluble forms.

Estimated parameters of total NO_3^- fertilizer application show an expected positive sign. The estimated parameters from the 2- to 5-mo lag of the fertilizer application show statistical significance at the 0.05 level. The parameter estimates using NO_3^- removed by the growing corn crop and crop harvest shows the expected negative sign but is not statistically significant. The estimated parameter of population is not statistically significant. This is not surprising because discharges of NO_3^- from a relatively stable population level are not likely to explain significant monthly variation in NO_3^- concentration levels in the river.

The last two columns in Table 1 report short-run and long-run implied elasticities of the mean equation of the GARCH model. We report short-run and long-run elasticity values only for the statistically significant variables calculated at their sample mean values. The estimated mean equation is explicitly constructed using lagged values of NO_3^- concentration and current and lagged values of a selected number of independent variables. The lagged values of the dependent variable are included to account for sluggish adjustment of NO_3^- concentration in response to changes in the explanatory variables. Hence, the estimated results in the study have an interesting separation of short- and long-run effects.

In the short run, a 10% increase in current month rainfall increases NO_3^- concentration by 1.3% Also, a 10% increase in previous month rainfall increases current NO_3^- concentrations by approximately 1.7%. A 10% increase in previous month temperature increases current month NO_3^- concentration by 6.1% in the Raccoon River in the short run. In addition, a 10% change in nitrogen fertilizer application in any of the prior 2- to 5-mo periods change NO_3^- concentration in the river by approximately 1% in the short run. Overall, this shows that, in the short run, temperature and rainfall have significant roles in determining the variations in NO_3^- concentrations that are observed in the Raccoon River.

When comparing long-run with the short-run elasticities for 1 mo lagged temperature, both estimates are very similar. However, the estimate for 1 mo lagged rainfall in the long run is larger than in the short run, indicating that the long-term rainfall pattern plays an important role in explaining the NO_3^- concentration pattern in the river. The long-run fertilizer application elasticities for the 2- to 5-mo lagged period are larger than for the short run. This indicates that there may be residual effects from fertilizer applications contributing to variations of in-stream NO_3^- concentration levels, the effects of which are captured within the lagged dependent variable.

Estimated parameters in the variance equation are not statistically significant, except for the intercept term (Table 1). The parameter estimates for one period-lagged squared error (ε_{t-1}^2) and one period-lagged conditional variance (σ_{t-1}^2) are not statistically significant. However, they are jointly statistically significant at the 5% level. The sum of these two estimated parameters is less than 1, indicating that the volatility of the NO_3^- concentrations in the Raccoon River represents a very stable system. The volatility in NO_3^- concentrations over the period from 1992 to 2008 does not tend to be explosive.

The overall predictive power (R^2) is 0.51, indicating that the model explains only 51% of total variation of NO_3^- concentration. Figure 5 compares the observed and corresponding predicted values of the NO_3^- concentration of the GARCH model. As a robustness check, we examined whether the parameters of our model are stable across various subsamples of our time series data. We followed one simple empirical technique. The total number of observations (n = 198) was partitioned into T_1 (n = 186; time period between 1992 and 2007) to be used for estimation and T_2 (n = 12; time period = 2008) to be used for testing and evaluation. An estimated model based on T_1 is used to predict the observations of T_2. We found that the calculated mean absolute percent error is 13.9%. However, we note that the estimated parameters in our study are based on a normal maximum likelihood (i.e., the distribution of one observation conditionally to the past is normal) and can be very sensitive to the presence of a few outliers in the sample. Modeling with isolated additive outliers is beyond the scope of this paper. We also did simple multicollinearity diagnostics and did not find any case to support perfect collinearity of the independent variables in the model.

Concluding Remarks and Policy Discussion

For the period of this study (1992–2008), we found no statistically significant increasing trend in NO_3^- concentrations in the Raccoon River. However, there are substantial significant intra-annual variations in NO_3^- concentrations and a very strong seasonal pattern. Overall, the data support the conclusion that this is a very stable biological system over multiple decades. Variations in rainfall and temperature contribute more to the monthly variation in NO_3^- concentration than do the changes in nitrogen application rates. The results indicate that timing of nitrogen fertilizer application has a significant explanatory role in determining monthly levels of NO_3^- concentration in the Raccoon River but that rainfall and temperature patterns are even more significant determinants of month-to-month variability. These results suggest that policymakers should consider giving higher priority to practices and interventions in the watershed aimed at addressing problems associated with erratic, seasonal rainfall patterns during the spring and summer months. Giving priority to these seasonal variables may be more effective at reducing peak NO_3^- concentration levels than those policies targeting nitrogen application rates on corn or the number of livestock within the watershed. Edge-of-field practices, such as strategically placed restored wetlands that maximize water retention time within the drainage system, could mitigate the effects of seasonal climatic variables, such as rainfall and temperature, on in-stream NO_3^- levels.

The development of environmental, land use, and water quality policies requires balancing many complementary and competing goals. The development of sound policy requires an understanding of the factors contributing to variations in water quality measures, such as in-stream NO_3^- concentration levels, to ensure the best use of limited resources. The policy-making process will be better informed as we improve our understanding of the causes of variation in water quality. Additional research

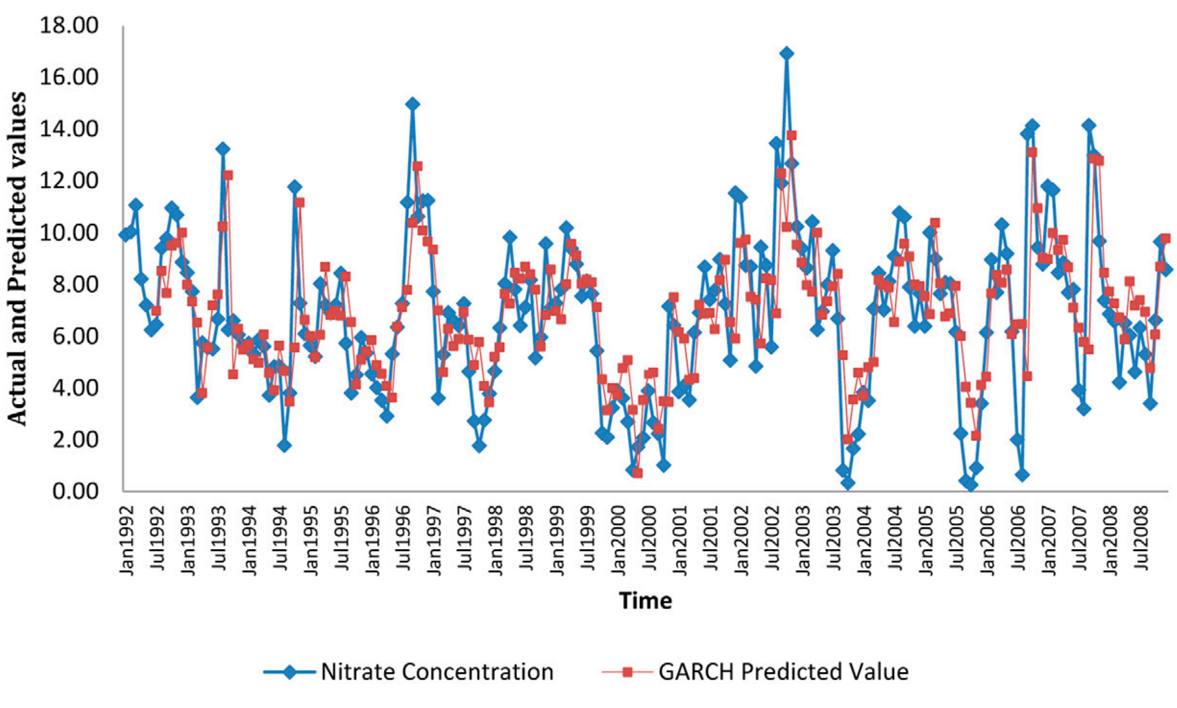

Fig. 5. A comparison of observed versus corresponding predicted values of NO_3^- concentration of Generalized Autoregressive Conditional Heteroscedastic (GARCH) model.

into the factors affecting variation of water quality measures, such as NO_3^- concentration, will allow for development of more cost-effective and efficient watershed management and allocation of scarce public and private resources. Greater knowledge will allow Iowa farmers to proactively participate in the process and consider adopting those best management practices that will most benefit the watershed.

This study has some limitations. We did not consider NO_3^- inputs to the watershed from legume fixation in the soil. Emphasis was placed on man-made commercial and manure fertilizer application within the watershed. We also did not consider the mass of NO_3^- exported in the stream because changes in mass can arise by a change in concentration, a change in flow, or both, and we could have flow changes that have no change in concentration and have different mass. This issue was beyond the specific focus of this study. This study only takes into account the grain NO_3^- uptake and ignores NO_3^- uptakes by the nongrain portion of the crop. Postharvest residue NO_3^- is likely accounted for with the variables for grain removal, temperature, and rainfall because the amount of residue is highly correlated to the amount of grain produced and because the timing of release of NO_3^- from the residue is a function of temperature and moisture. In a time series analysis, the inclusion of highly correlated variables can cause problems with parameter coefficient estimation. One way to deal with this is to drop one of the highly correlated variables because the effects of the dropped variable will be manifest in the remaining variable. The parameters of one period lagged squared error (ε_{t-1}^2) and one period lagged conditional variance (σ_{t-1}^2) are known as GARCH terms. Because of the individual statistically insignificant results of the GARCH terms in this study, one may reasonably argue that there is no value in considering the GARCH (1, 1) model used in this study. The future plan is to fit a much simpler time series model, such as a seasonal ARIMA model, so that we can compare the results with the GARCH (1, 1).

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